

## CHAPTER 8

# TROPOSPHERIC SCATTER SYSTEM DESIGN

Given the fundamental plans and study results, and the profiles, data and other information obtained from the field investigation, the next order or procedure concerns the transmission engineering plans, calculations and design specifications. Some of this work, such as planning, is actually accomplished prior to the route selection work. After the field investigation is finished, the final calculations concerning antennas, interference, system and channel noise, distortion and propagation reliability are made. If the final sites have not been selected from the field data at this point, this must be done prior to much of the other work. Also at this point it may be important that information about the choice of sites be made available to those responsible for obtaining the necessary property, as failure to obtain one site may affect some of the other selections.

The final objective for any microwave system is that it provides the best distortion-free and interference-free service continuity for the type of service to be assigned, and within the framework of the available economics.

Overall reliability or service continuity involves not only equipment failure rates and power failures, but also the propagation performance and the individual paths. This involves antenna sizes and elevations, frequency or space separations in diversity systems, path lengths and frequency-attenuation relationships. It also includes fading margins which, in addition to path parameters, are affected by noise figure, transmitter power, and attenuation of waveguide and filter arrangements.

Distortion may occur in the radio path, but more often it occurs due to poor return loss of amplifier components, waveguide filters and antennas. Also the characteristics of switching devices and/or combiners are involved.

System noise is affected by the same things which, in addition to interference, can have an adverse effect on overall system performance.

### 8.1 SYSTEM CALCULATIONS

Procedures for designing a tropospheric scatter communications circuit can be organized into five major steps. These are:

- o The determination of the basic system requirements (the communications need)
- o The preliminary analysis of the proposed system configuration to determine path lengths and possible site locations (feasibility study)

- o The field surveys of the proposed sites and the paths between to accurately determine coordinates, and elevations of salient features and provide information not evident from a map study (site survey)
- o Using the results of the first three steps, a final prediction of the link performance is made, based upon the type of equipment to be used, the path length, and channel capacity
- o The actual installation procedures.

The first two steps were discussed in chapter 6, the field survey requirements are listed in Appendix E, and the final prediction is described in the following paragraphs.

The final design calculations are to be based upon the best information obtainable but shall have an accuracy not less than:

- o Coordinates to third order accuracy
- o Elevations to nearest 5 meters
- o Distances to 0.1 miles
- o All azimuths to 10 seconds.

Maps utilized shall have a scale not less than 1 in 25,000 with contours at 5 meter intervals. In areas where maps of this scale are not available a scale of 1 in 100,000 with contours at not more than 30 meter intervals may be used with care.

To clarify the use of the formulas and methods, a sample link calculation shall be made. The preliminary studies showed a transhorizon link was feasible between Dallas and Austin, Texas. Based upon the site survey the coordinates of the sites are as shown in figure 8-1.

Using figure 2-8 or 2-9 the radio refractivity  $N_0$  is determined as 315.

From the average heights above sea level of the antennas  $h_{ts} = 280.4$  m and  $h_{rs} = 243.9$  m,

the average antenna height

$$h_s = \frac{h_{ts} + h_{rs}}{2}$$

$$h_s = 261.9 \text{ m}$$

MICROWAVE PATH DATA CALCULATIONS									
1	SITE		DALLAS		AUSTIN				
2	LATITUDE		32° 28' 13" N		30° 01' 48" N				
3	LONGITUDE		96° 28' 48" W		97° 28' 13" W				
4	ELEVATION		2704 m		2341 m				
5	TOWER HEIGHT		10 m		9.8 m				
6	TOWER TYPE								
7	AZIMUTH FROM TRUE NORTH		149° 23' 28"		18° 23' 38"				
8	PATH LENGTH		283.1 km		283.1				
9	PATH ATTENUATION (1- $\sigma$ )		238.8 dB		238.8				
10	RIGID WAVEGUIDE		Ft.		100				
11	FLEXIBLE WAVEGUIDE		Ft.		-				
12	WAVEGUIDE LOSS		dB		1.4				
13	CONNECTOR LOSS		dB		3				
14	CIRCULATOR OR HYBRID LOSS		dB		1.0				
15	RANDOM LOSS TYPE*		dB						
16	NEAR FIELD LOSS		dB						
17	CLOSE COUPLING LOSS (SCATTER)		dB		13.2				
18	TOTAL FIXED LOSSES		dB		18.2				
19	TOTAL LOSSES		dB		256.8				
20	PARABOLA HEIGHT		Ft.						
21	PARABOLA DIAMETER		Ft.						
22	REFLECTOR HEIGHT		30 Ft.						
23	REFLECTOR SIZE TYPE		Ft.						
24	PARABOLA - REFLECTOR SEP.		Ft.						
25	DIV. IMP. FACTOR, QUAD. DIV.		dB		7				
26	ANTENNA SYSTEM GAIN		dB		25				
27	TOTAL GAIN		dB		111				
28	NET PATH LOSS		dB		145.2				
29	TRANSMITTER POWER (20 kw)		dBm		+77				
30	MED. RECEIVED POWER ( $\pm 2$ dB)		dBm		-88.1				
31	RECEIVER NOISE THRESHOLD		dBm		-104				
32	THEORETICAL RF CN RATIO		dB		32.9				
33	FM IMP. THRESHOLD (dB)		dBm		-84				
34	FADE MARGIN (to FM Imp. Thresh.)		dB		32.9				
35	RELIABILITY		%		0				
36	POLARIZATION								
37	PROFILE NUMBER								
CUSTOMER U. S. NAVY PROJECT NO. _____ FREQUENCY 5000 MHz SYSTEM _____ EQUIPMENT _____ LOADING _____ CHANNELS OF _____ (dBm)									

Figure 8-1. Microwave Path Data Calculation Sheet

and from equation 2-12

$$N_s = N_o \exp(0.03222 h_s)$$

$$N_s = 306$$

The effective earth's radius  $a = 8580$  km is determined from figure 6-2. Using the map study method specified in section 6.2.3 the path profile is plotted as shown in figure 8-2. The troposcatter path geometry is shown in figure 8-3.

The tropospheric path angle (or scatter angle)  $\theta$  is calculated as shown in figure 8-4. The parameters not calculated on the page are easily determined from the previous calculations or measurements. The correction terms  $\Delta\alpha_o$  are determined from figures 6-18 and 6-19 as follows:

- o Enter figure 6-18 with  $\theta_{ot}$  and  $d_{st}$  and obtain  $\Delta\alpha_o$  (for  $N_s = 301$ )
- o If  $N_s$  is other than 301, enter figure 6-19 and obtain  $C(N_s)$
- o Multiply (for  $N_s = 30$ ) by  $C(N_s)$  to obtain

The median transmission loss ( $L_{bsr}$ ) calculation is shown in figure 8-5. The attenuation function  $F(0d)$  is obtained from any one of figure 806 through 8-11 depending on the required  $N_s$ . The scattering efficiency factor  $F_o$  is usually small. It exceeds 2 dB only for distances and antenna heights so large that  $h_o$  exceeds  $h_i$  by more than 3 kilometers. The total loss in the example of figure 8-5 is 238.6 dB which is entered in item 9 of figure 8-1.

Other losses to be tabulated include:

100 feet of RG 49 waveguide for each terminal which has (from table 8-1)

1.4 dB per 100 feet at 5 GHz, waveguide connectors 0.3 dB per terminal and 1.0 dB for the circulator at the receiving end.

The antennas proposed for this link are 30 feet in diameter with a gain of 52 dB and a beamwidth  $\Omega$  of 0.49 degrees (8.5 milliradians). The individual gains are entered in item 23, the diversity factor for quadruple diversity of 7 dB from figure 7-1 is entered in item 22, then the totals of these in item 24.

One additional loss must be considered that is the scatter coupling loss.

The ratio of  $\frac{\theta}{\Omega}$  is obtained.

In this case

$$\frac{\theta}{\Omega} = \frac{32.151}{8.5} = 3.79.$$

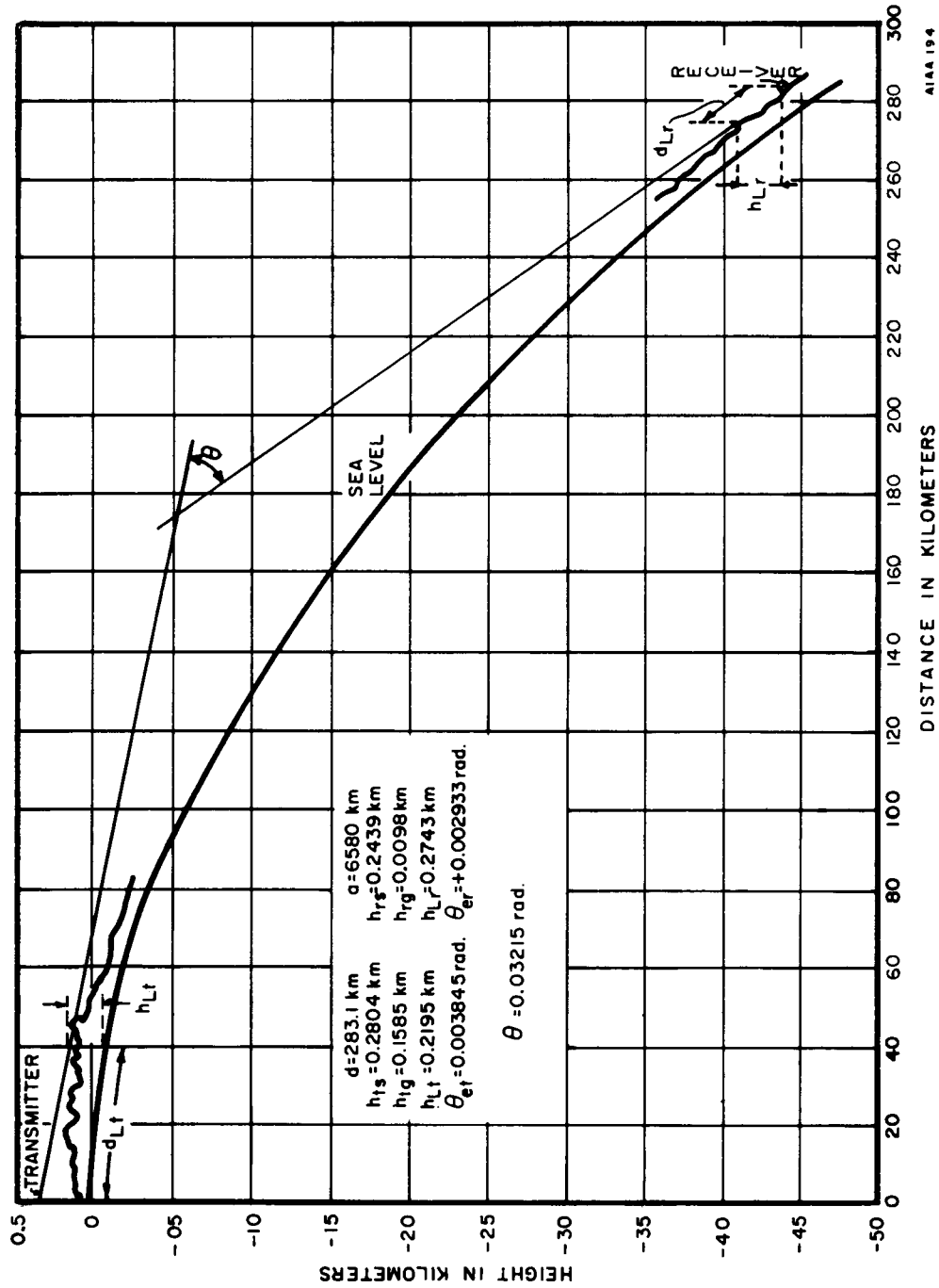


Figure 8-2. Profile of a Transhorizon Path

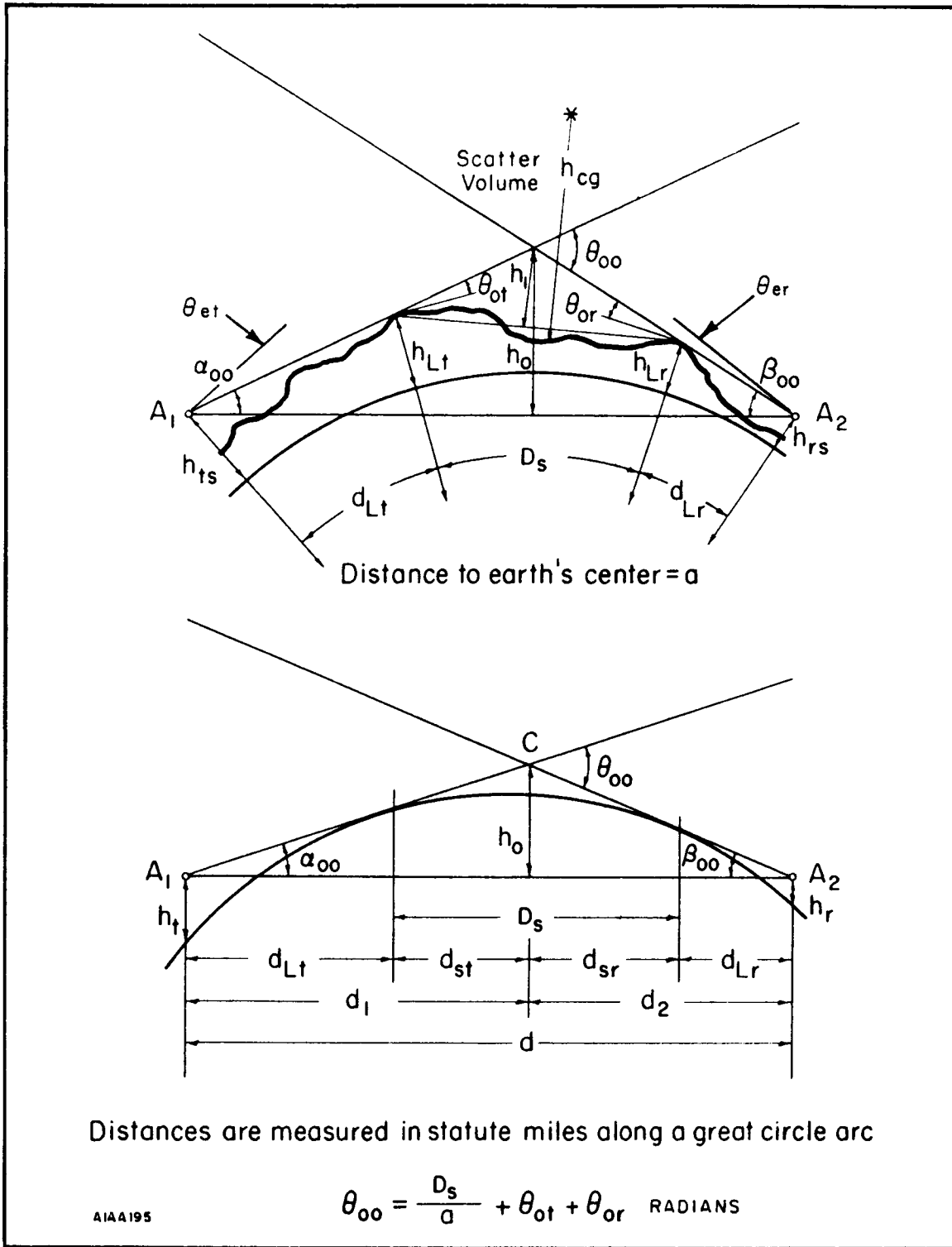


Figure 8-3. DCAC-330-175-1 Path Geometry

(EXISTING TROPOSCATTER PATH)	
$d = 283.1 \text{ km}$ $a = 8580 \text{ km}$	
AUSTIN	DALLAS
$h_{ts} = 280.4 \text{ m}$ $h_{Lt} = 219.5 \text{ m}$ $h_{te} = 135 \text{ m}$ $d_{Lt} = 39.6 \text{ km}$ $d_{st} = 130.72 \text{ km}$	$h_{rs} = 243.9 \text{ m}$ $h_{Lr} = 274.3 \text{ m}$ $h_{re} = 9.8 \text{ m}$ $d_{Lr} = 8.8 \text{ km}$ $d_{sr} = 103.95 \text{ km}$
$\theta_{et} = \frac{h_{Lt} - h_{ts}}{d_{Lt}} - \frac{d_{Lt}}{2a}$ $= \frac{219.5 - 280.4}{39600} - \frac{39.6}{2(8580)}$ $= -3.845 \text{ mr}$	$\theta_{er} = \frac{h_{Lr} - h_{rs}}{d_{Lr}} - \frac{d_{Lr}}{2a}$ $= \frac{274.3 - 243.9}{8800} - \frac{8.8}{2(8580)}$ $= +2.933 \text{ mr}$
$x = \frac{d}{2a} + \frac{h_{ts} - h_{rs}}{d}$ $= \frac{283.1}{2(8580)} + \frac{280.4 - 243.9}{283.1}$ $= 16.679 \text{ mr}$	$y = \frac{d}{2a} - \frac{h_{ts} - h_{rs}}{d}$ $= \frac{283.1}{2(8580)} - \frac{(280.4 - 243.9)}{283.1}$ $= -10.013 \text{ mr}$
$\theta_{ot} = \theta_{et} + \frac{d_{Lt}}{a}$ $= -3.845 + \frac{39.6}{8580}$ $= .768 \text{ mr}$	$\theta_{or} = \theta_{er} + \frac{d_{Lr}}{a}$ $= 2.933 + \frac{8.8}{8580}$ $= 3.961 \text{ mr}$
$\Delta\alpha \cong 0$ FROM FIGURES 6-18 AND 6-19	$\Delta\beta \cong 0$ FROM FIGURES 6-18 AND 6-19
$\alpha_o = \theta_{et} + x + \Delta\alpha_o$ $= 3.845 + .1455 + 0$ $= 12.834 \text{ mr}$	$\beta_o = \theta_{er} + y + \Delta\beta_o$ $= +2.933 - .1125$ $= 19.317 \text{ mr}$
$\theta_{oo} = \theta = \alpha_o + \beta_o = 12.834 + 19.317 = \underline{32.151 \text{ mr}}$	

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Figure 8-4. Tropospheric Path Angle Computations (Milliradians)

$$L_{bsr} = 30 \text{ LOG } f - 20 \text{ LOG } D + F(\theta d) - F_0 + H_0 + A_d \text{ dB}$$

$\theta d$ IN RADIANS (283.1) (32.151) ( $10^{-3}$ )	9.10	
PATH ASYMMETRY FACTOR $S = \frac{\alpha_o}{\beta_o} = \frac{12.834}{19.317}$	.664	
ATTENUATION FUNCTION $F(\theta d)$ IN dB FROM FIGURE 8-6, 7, 8, OR 9		167 dB
30 LOG F IN dB = 30 LOG 5000		111 dB
- 20 LOG d IN dB = - 20 LOG 283.1		-49 dB
$h_o = \frac{S d \theta}{(1+S)^2}$ IN km = $\frac{.664 (9.10)}{(1 + .664)^2}$	2.18 km	
$r_1 = 41.92 \theta f h_{te} = 41.92 (.0321) (5000) (.135)$	19.01	
$r_2 = 41.92 \theta f h_{te} = 41.92 (.0321) (5000) (.0098)$	1.38	
$q = \frac{r_2}{sr_1} = \frac{1.38}{.664 (19.01)}$	1.09	
$\eta_s$ FROM FIGURE 6-22	1.1	
$H_0 = \frac{H_0(r_1) + H_0(r_2)}{2} + \Delta H_0$ IN dB $= \frac{.15^2 + 13.5}{2} + .61$ $H_0(r_1) \text{ \& } H_0(r_2)$ FROM FIGURE 8-10 ; $\Delta H_0$ FROM FIGURE 8-11		7.4 dB
$D_s = d - d_{L_t} - d_{L_r}$ IN km = 283.1 - 39.6 - 8.8 km	234.7	
$L_1 = \frac{S D_s \theta}{(1+S)^2}$ IN km = $\frac{.664 (234.7) (.0321)}{(1 + .664)^2}$ km	1.82	
$F_0 = 1.086 \left( \frac{\eta_s}{h_o} \right) (h_o - h_1 - h_{L_t} - h_{L_r})$ dB $= 1.086 \left( \frac{1.1}{2.18} \right) (2.18 - 1.82 - .219 - .274)$		≈ 0
$A_d$ FROM FIGURE 4-6		2.2 dB
$L_{bsr}$		238.6 dB AIAA197

Figure 8-5. Computation of Long-Term Median Transmission Loss Trpospheric Scatter



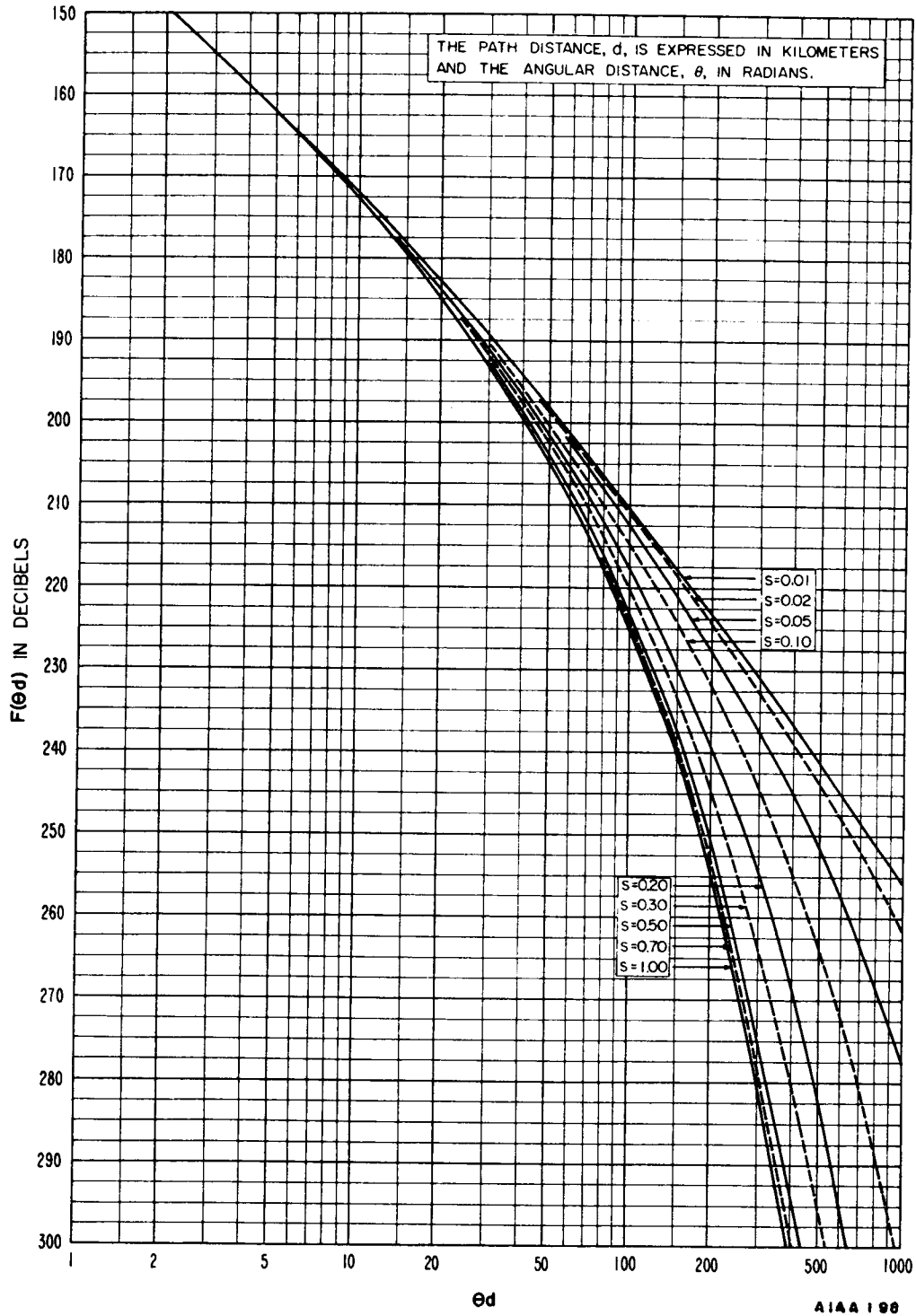


Figure 8-6. The Function  $F(\theta d)$  for  $N_s = 250$

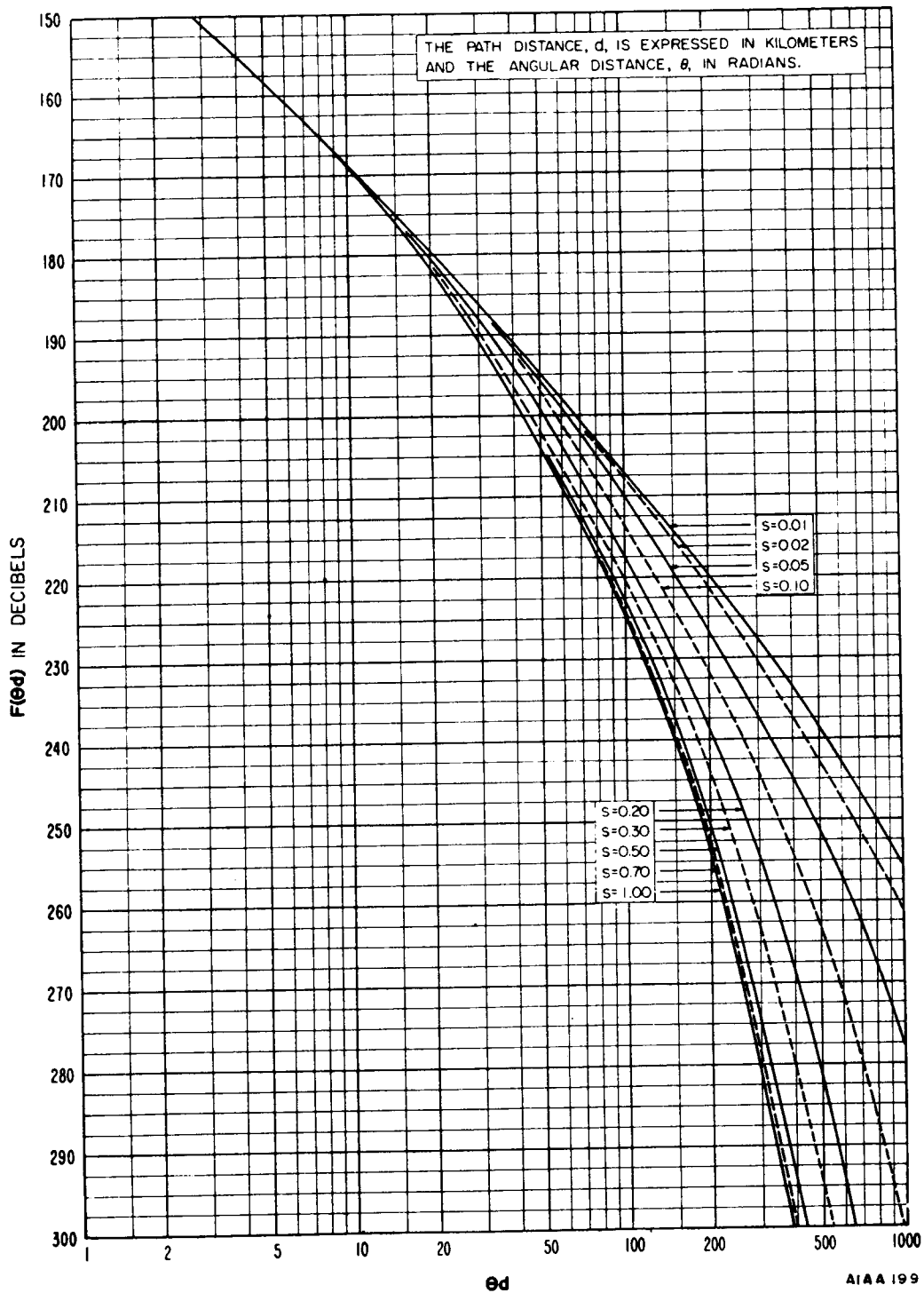


Figure 8-7. The Function  $F(\theta d)$  for  $N_s = 301$

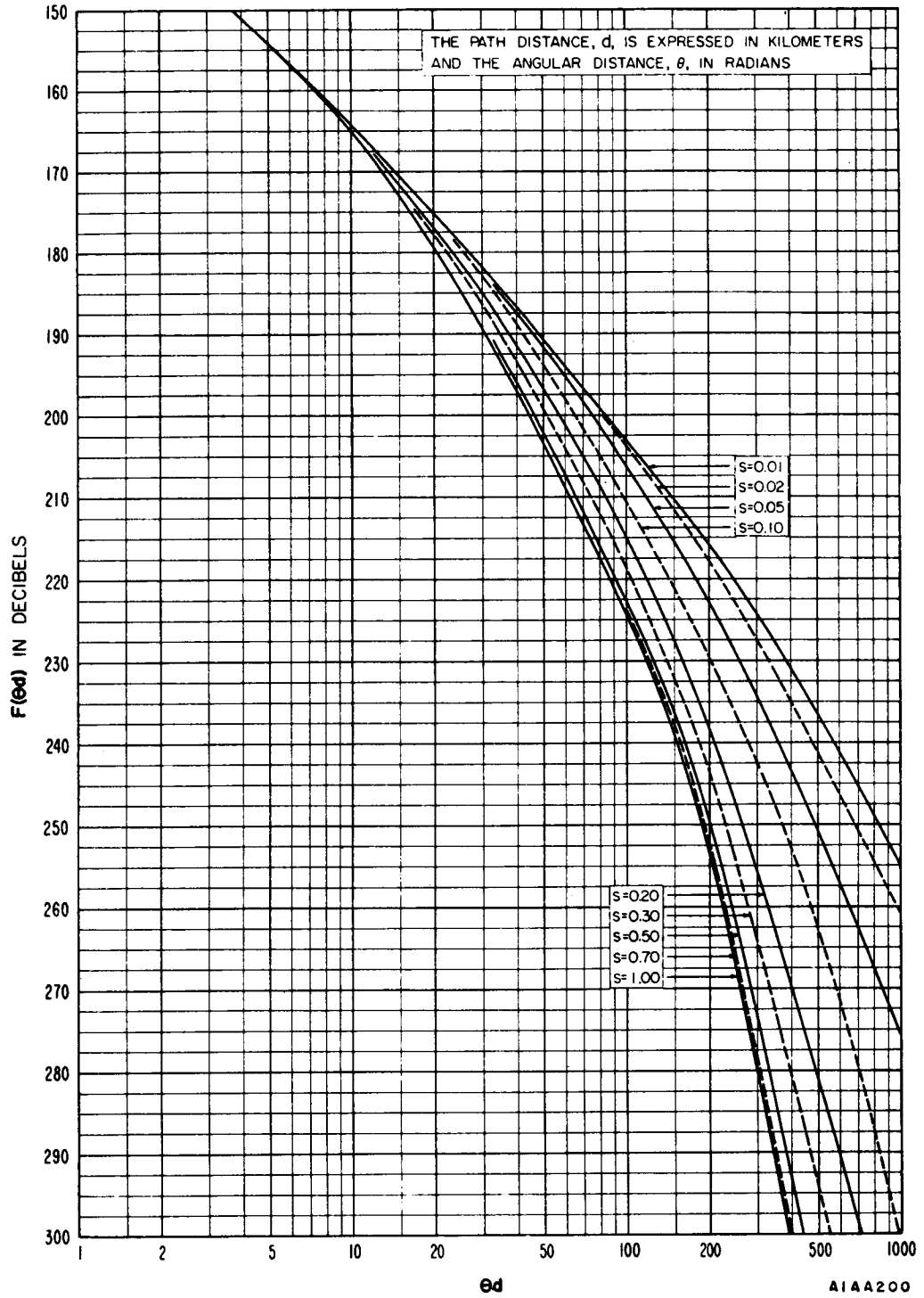


Figure 8-8. The Function  $F(\theta d)$  for  $N_S = 350$

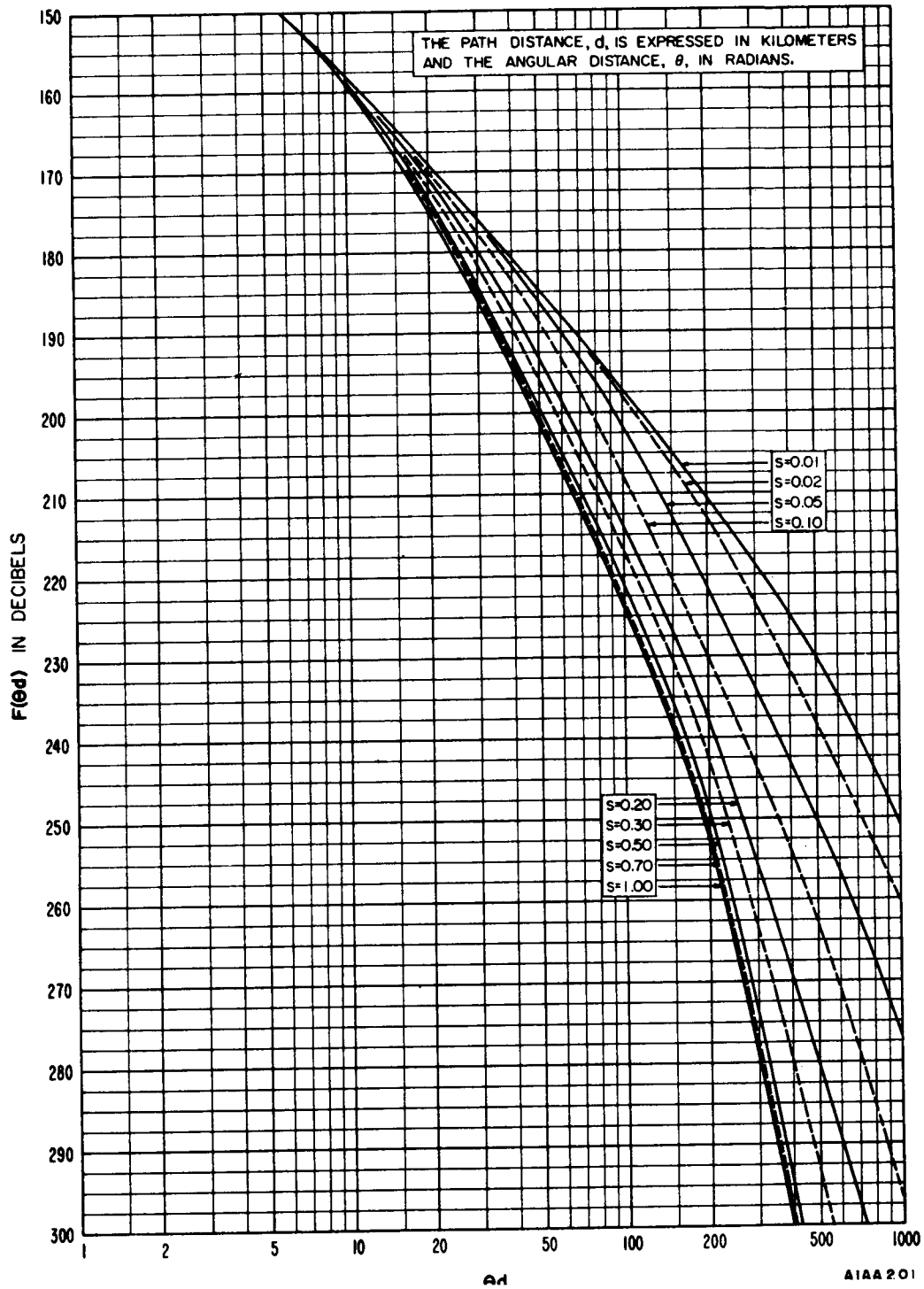


Figure 8-9. The Function  $F(\theta d)$  for  $N_s = 400$

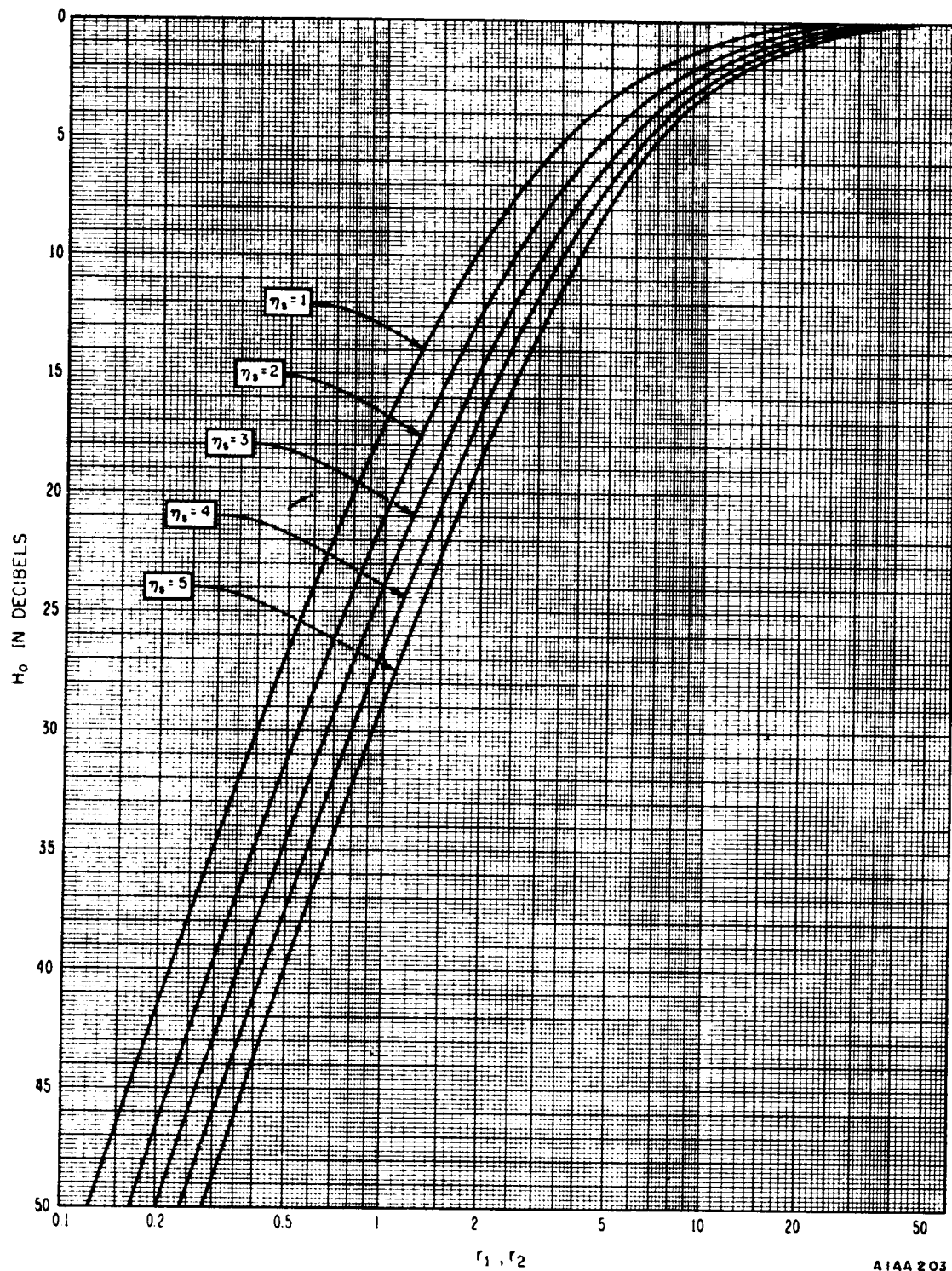
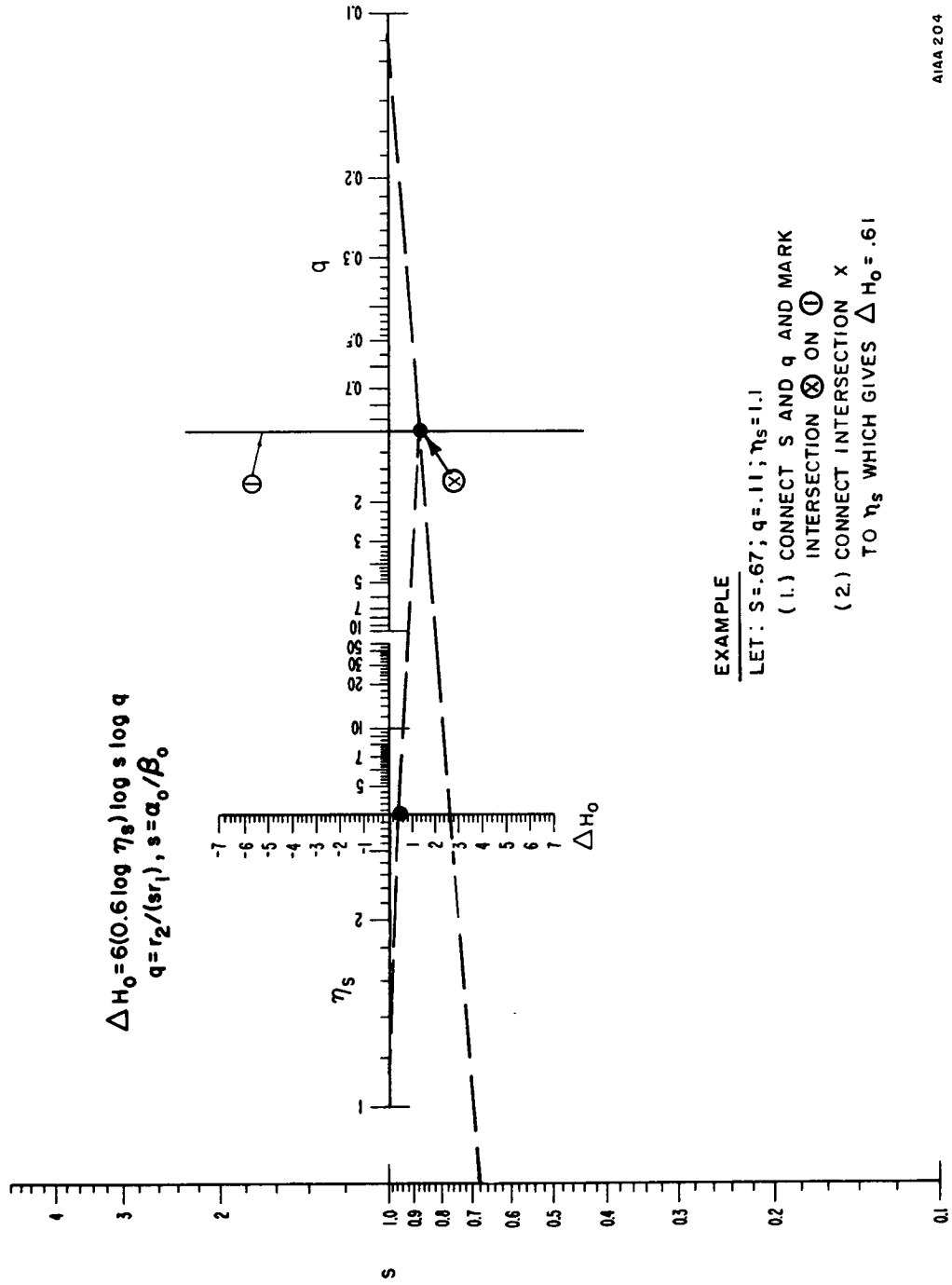


Figure 8-10. The Frequency Gain Function,  $H_0$



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Figure 8-11. Nomogram to Determine  $\Delta H_0$

Table 8-1. Standard Waveguides

EIA WAVEGUIDE DESIGNATION	JAN WAVEGUIDE DESIGNATION	OUTER DIMENSIONS AND WALL THICKNESS (IN INCHES)	FREQUENCY RANGE IN GIGAHERTZ FOR DOMINANT (TE <sub>1,0</sub> ) MODE	CUTOFF WAVELENGTH λ <sub>c</sub> IN CENTIMETERS FOR TE <sub>1,0</sub> MODE	CUTOFF FREQUENCY f <sub>c</sub> IN GIGAHERTZ FOR TE <sub>1,0</sub> MODE	THEORETICAL ATTENUATION, LOWEST TO HIGHEST FREQUENCY IN dB/100 FT	THEORETICAL POWER RATING IN MEGAWATTS FOR LOWEST TO HIGHEST FREQUENCY*
WR-770	RG-205/U <sup>W</sup>	7.950X4.100X0.125	0.96-1.45	39.1	0.767	0.201-0.136	17.2-24.1
WR-650	RG-69/U	6.660X3.410X0.080	1.12-1.70	33.0	0.908	0.317-0.212	11.9-17.2
WR-510	-	5.260X2.710X0.080	1.45-2.20	25.9	1.16	-	-
WR-430	RG-104/U	4.460X2.310X0.080	1.70-2.60	21.8	1.375	0.588-0.385	5.2-7.5
WR-340	RG-112/U	3.560X1.860X0.080	2.20-3.30	17.3	1.735	0.877-0.572	-
WR-284	RG-48/U	3.000X1.500X0.080	2.60-3.95	14.2	2.08	1.102-0.752	2.2-3.2
WR-229	-	2.418X1.273X0.064	3.30-4.90	11.6	2.59	-	-
WR-187	RG-49/U	2.000X1.000X0.064	3.95-5.85	9.50	3.16	2.08-1.44	1.4-2.0
WR-159	-	1.718X0.923X0.064	4.90-7.05	8.09	3.71	-	-
WR-137	RG-50/U	1.500X0.750X0.064	5.85-8.20	6.98	4.29	2.87-2.30	0.56-0.71
WR-112	RG-51/U	1.250X0.625X0.064	7.05-10.00	5.70	5.26	4.12-3.21	0.35-0.46
WR-90	RG-52/U	1.000X0.500X0.050	8.20-12.40	4.57	6.56	6.45-4.48	0.20-0.29
WR-75	-	0.850X0.475X0.050	10.00-15.00	3.81	7.88	-	-
WR-62	RG-91/U	0.702X0.391X0.040	12.40-18.00	3.16	9.49	9.51-8.31	0.12-0.16
WR-51	-	0.590X0.335X0.040	15.00-22.00	2.59	11.6	-	-

\*For these computations, the breakdown strength of air was taken as 15,000 volts per centimeter. A safety factor of approximately 2 at sea level has been allowed.

<sup>W</sup>Aluminum, 2.83X10<sup>-6</sup> ohm-cm resistivity. <sup>†</sup>Silver, 1.62X10<sup>-6</sup> ohm-cm resistivity. <sup>‡</sup>Silver, with a circular outer cross section of 0.156-inch diameter and a rectangular cross-sectional bore of indicated dimensions. All other types are of a Cu-Zn alloy, 3X10<sup>-6</sup> ohm-cm resistivity.

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Figure 6-23 gives this loss as 13.5 dB which is entered in item 15.

The total path losses then becomes 256.5 dB (items 9 and 16) less the total gain of 111 dB (item 24) giving a net path loss of 145.5 dB (item 25). If a 1 kW (+77 dBm) transmitter is used the median received signal (item 27) becomes -68.1 dBm.

The receiver bandwidth is considered next. Using a 72 voice channel system with a peak deviation  $\Delta F_p$  of 1.2 MHz (modulation index of 3), the maximum modulating frequency is about 360 kHz. This is computed as follows:

$$\text{Minimum modulating frequency} = 60 \text{ kHz}$$

$$\text{Voice channel bandwidth } 72 (4 \text{ kHz}) = 288 \text{ kHz}$$

$$\text{Spacing between supergroups} = \underline{12 \text{ kHz}}$$

$$\text{The maximum modulating frequency } F_m = 360 \text{ kHz}$$

The Bandwidth

$$BW = 2 (\Delta F_p + F_m)$$

$$BW = 2 (1.2 \text{ MHz} + 360 \text{ kHz}) = 3.12 \text{ MHz}$$

The receiver noise threshold is obtained from

$$\text{Threshold} = .174 + \log BW + (\text{Receiver Noise figure in dB})$$

$$= .174 + 10 \log 3.12 \times 10^6 + (5)$$

$$= .174 + 65 + 5 = .104 \text{ dBm}$$

which is entered in item 28 of figure 12-8 providing a theoretical carrier to noise ratio of 35.9 dB. The FM threshold is 10 dB above the receiver noise threshold or -94 dBm providing a fade margin of 25.9 dB.

After reliability considerations have been established and a favorable system design completed, it is necessary to compute the expected channel noise. According to the DCA System Performance Specifications, the channel noise objective is 38 dBaO. The requirement states that:

... noise in any channel shall not exceed 38 dBa median at zero relative level (25,000 picowatts) in any channel during the worst month, and shall not exceed 49 dBa at zero relative level (316,000 picowatts) in any channel for more than 1.0 percent of the worst month.

The channel noise (Signal-to-Noise ratio (S/N)) may be computed after the Carrier-to-Noise (C/N) ratio of the path has been determined. The relationship between channel



S/N and system C/N in an FM system is determined primarily by the bandwidth required for the particular type of information being transmitted and the degree of deviation produced in the system.

The Carrier-to-Noise defines the power relationship that exists between the median received signal level and the noise.

The signal to Noise ratio

$$S/N = C/N + 20 \log (\text{Mod index}) + 10 \log \frac{BW}{2bw} + PF - L - MUX$$

where,

C/N = Total Median Carrier-to-Noise Ratio

BW = Receiver IF Bandwidth

bw = Voice Channel Bandwidth

L = Channel Loading Factor

PF = Pre-emphasis Gain

MUX = Multiplex Equipment Noise Insertion

For the system under consideration

Modulation Index = 3

C/N = 25.5 dB

BW = 3.2 MHz

bw = 4 kHz

PF = 4 dB

L = 10.8 dB (See figure 7-3)

MUX = 2 dB (average factor)

Thus,

$$\begin{aligned} S/N &= 35.9 + 20 \log 3 + 10 \log \left( \frac{3.2 \times 10^6}{8 \times 10^3} \right) + 4 - 10.8 - 2 \\ &= 20 \log 3 + 10 \log (4 \times 10^2) + 27.1 \end{aligned}$$

$$\begin{aligned}
 &= (20) (.466) + (10) (2.602) + 27.1 \\
 &= 9.54 + 26.02 + 27.1 \\
 &= 62.76
 \end{aligned}$$

Thus, the S/N ratio has been computed. Before proceeding to the determination of the channel noise, it is important to stop briefly consider the meaning of the S/N ratio.

The term signal-to-noise ratio (S/N) originated in single-channel communications practice and generally took into consideration only the background or residual noise in a single radio channel. With the growth of multichannel communications, it is also used to express the total intermodulation and residual noise in a single radio channel and is frequently referred to as "per-channel flat signal-to-noise ratio." Basically, it expresses the ratio, in decibels, of signal power to total noise power in a channel. It does not take into account the actual interfering effect of the noise on the signal the circuits.

The channel noise factor is expressed in dBaO. Decibels adjusted, or dBa, originated in the telephone industry as an expression of overall system noise performance. Strictly speaking, the term dBa implies that the frequency equipment used is "FIA" weighting. This method of noise performance is especially practical. It takes into account not only special types of noise or noise in particular items of equipment, but also the effects of all system noise.

By definition, dBa refers to decibels of noise power above a reference noise power, with an adjustment factor included to compensate for weighting. Even though the equipment from which the FIA weighting was derived has been superseded by newer equipment having better performance, FIA weighting continues to be used extensively because it provides a very close approximation to the performance of most of the world's telephone equipment.

The reference noise power to which dBa is referred is -85 dBm. To obtain dBaO, it is only necessary to calculate how many dB above this reference power the signal is. For flat voice channels, the corrected reference level is  $-85 + 3$  or -82 dBm. Therefore, in this case

$$\text{dBaO} = 82 - (\text{S/N}) = 82 - 62.76 = 19.24 \text{ dBaO}$$

The path length in question is 283.1 kilometers which is 283.1 (.54) or 153 nautical miles.

The DCA standard allows noise N for a troposcatter link to be

$$N = \frac{L}{6000} \times 20,000 \text{ pWpO where } L \text{ is in nautical miles}$$

therefore

$$N = 3.33 (153) = 510 \text{ pWpO}$$

and

$$\begin{aligned} N \text{ (dBaO)} &= 10 \log \text{ pWp} - 6 \text{ dB} \\ &= 21 \text{ dBaO} \end{aligned}$$

If the value of the channel noise factor did not meet the minimum specified for the system, it would be necessary to increase the basic peak channel deviation, or the pre-emphasis, or base the signal reliability on a greater carrier-to-noise ratio. The choice will depend on the flexibility of the particular equipments involved. The effect of adjusting the deviation ratio on the bandwidth is shown in figure 7-4.

The system calculations presented in this section are provided as a guide and are a compilation of the most recent and reliable information currently available.

## 8.2 FREQUENCY PLANNING

In the design of any microwave communications system, it is necessary to develop a plan of frequency allocation that will preclude the possibility of interference. Such interference may be defined as the reception of an undesired signal with, or in place of, the desired signal. This undesired signal, or interference, should be considered in terms of its source and permissible level at the receiver.

### 8.2.1 Types of Undesired Signals

There are three types of undesired signals which must be considered by the microwave system planner, two of which are directly under his control.

- o Signals arriving at two or more receivers from two or more transmitters operating from the same location and in the same direction, that is, signals traveling parallel paths. These signals will arrive at approximately the same signal level, and will be affected equally by any fade that may occur along their path assuming that their frequency separation is not too great). These parallel signals will cause interference at the receivers unless the transmitting frequencies are chosen with the RF and IF rejection characteristics of the particular equipment in mind.

- o Signals from other transmitters at the same station, or at other stations in close proximity to the receivers. The desired signal, in this case, may be very weak as compared with the signal radiated from the nearby transmitter (for example, -75 dBm for the desired signal as compared with 0 dBm for the undesired signal). The undesired signal is usually not subject to atmospheric fading, as is the desired signal. Allowing for a fading margin of 30 dB, the desired signal level might be as low as -105 dBm. Because of these factors, the frequency separation between the

undesired locally transmitted signal and the desired received signal must be great enough to provide at least 25 dB attenuation of the undesired signal below the minimum level of the desired signal.

o Signals originating from sources external to, or unrelated to, the microwave system under consideration. These undesired signals are the most difficult to eliminate. Military microwave systems, or commercial systems operating in the vicinity of military installations, may have interference from certain types of radar or other UHF or SHF equipment. In some instances, an undesired signal may be the fundamental frequency of the radar equipment, and, in certain types of radar, the peak amplitude of this signal may be as much as 60 dB above the peak RF output of the microwave equipment. Since it is improbable that a change in radar frequency can be effected, it follows that the microwave system frequency allocation must be reconsidered.

In the case of interference resulting from harmonics of nearby transmitters operating on a lower frequency, it is necessary to locate the offending equipment and attempt modifications or adjustments to suppress or prevent the generation of harmonics. If this cannot be done, it will become necessary to employ harmonic waveguide filters to eliminate the interference. Problems of this nature must be solved on an individual basis through cooperation with the cognizant government or commercial agency.

A more complete discussion of these and other types of interference can be found in chapter 3.

#### 8.2.2 Frequency Assignment

When developing a radio-frequency allocation plan for a microwave communication system, allowance should be made for the maximum number of channels that may be required by future expansion. This will permit orderly system expansion with the minimum amount of modification, and will eliminate major readjustments which might otherwise be required. The frequency assignment requirements for military objectives specified in DCAC-330-175-1 include:

a. The unit of frequency separation shall be .08 MHz and the spacing between frequency allocations used in a given system shall be an integral multiple of 0.8 MHz.

b. The minimum separation between a transmit and receive carrier frequency of the same polarization on the same antenna shall be 120 MHz.

c. Where two frequency channels are handled on separate antennas, or at different polarizations, the frequency separation in (b) above may be reduced by an amount corresponding to the increased loss between the two frequencies, but shall not be less than 50 MHz.

d. The minimum separation between a transmit and receive carrier frequency at a single station shall be 50 MHz, but in any case, an integral multiple of 0.8 MHz.

e. To avoid interference within a single station, separation of the transmit-receive frequencies shall not be near the first IF frequency of the receiver. The minimum separation of transmit or receive carrier frequencies shall be seven units (5.6 MHz) for systems with 36 channels or less. (Table 8-2 shows the recommended separation for a larger number of channels.)

Table 8-2. Transmit (or Receive) Frequency Separations

MAXIMUM NUMBER OF CHANNELS	MAXIMUM IF BAND- WIDTH	FREQUENCY SEPARATION
36 - - - - -	3 MHz	5.6 MHz
60 - - - - -	6 MHz	11.2 MHz
120 - - - - -	10 MHz	16.8 MHz

### 8.2.3 Frequency Plan

The frequency channels shall be assigned on a hop-by-hop basis such that the median value of an unwanted signal in the receiver, due to using the same or adjacent frequency channels in two relay sections, shall be at least 10 dB below the inherent noise level of the receiver. Figure 8-12 depicts a frequency plan recommended by DCA Cir. 330-175-1.

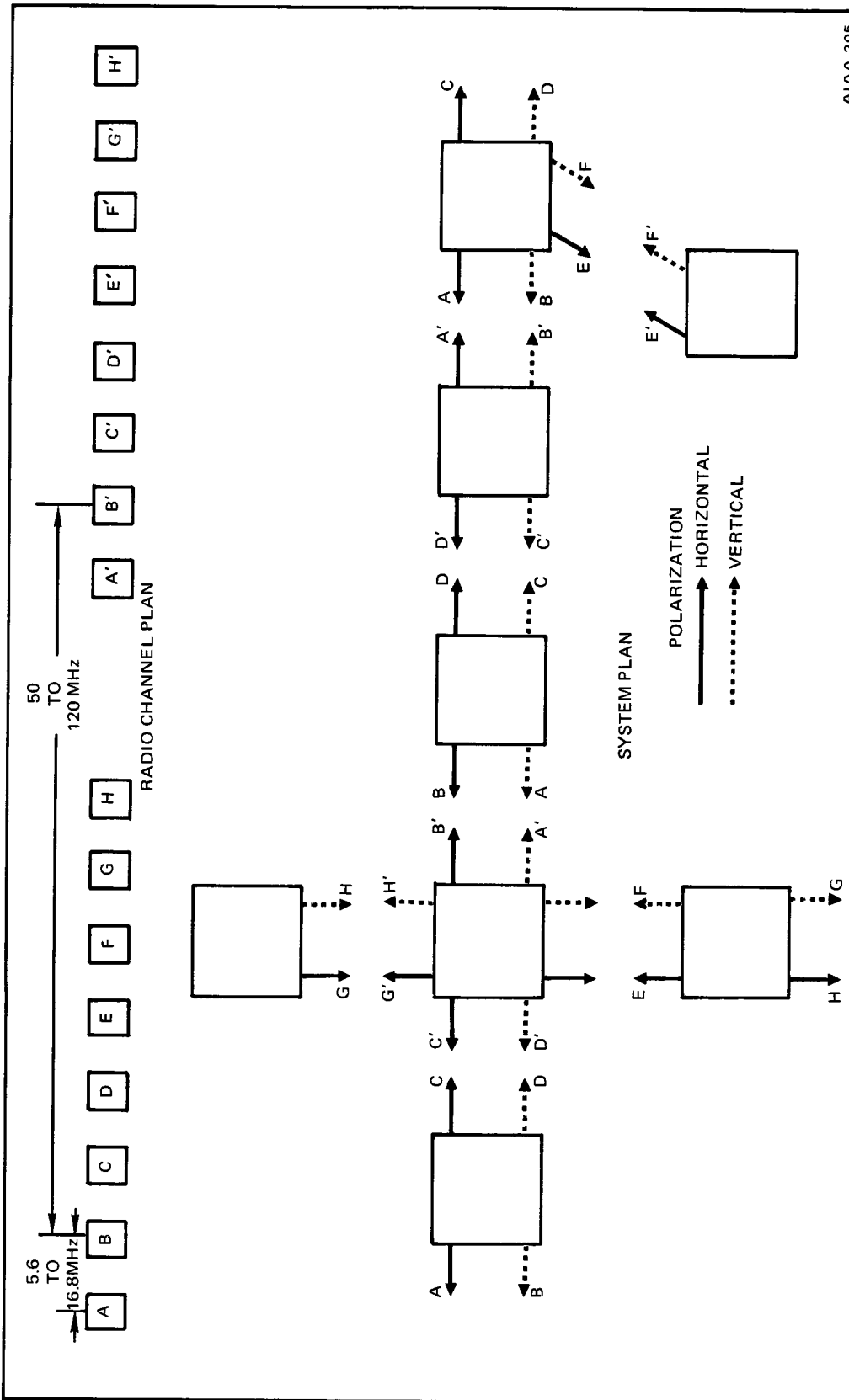
Within the Navy, responsibility for the procurement, assignment, and protection of radio frequencies is assigned to the Chief of Naval Operations. A frequency allocation must be approved prior to the procurement or installation of any C-E equipment designed to radiate or receive electromagnetic energy. For further information see NAVELEX 0101, 106, "Electromagnetic Compatibility and Electromagnetic Radiation Hazards."

Table 8-3 lists the microwave bands available for government services within the United States. Frequency assignments outside of these bands for use in the U. S. requires FCC approval. All frequency assignments for locations outside the United States are assigned by the host country.

A basic computer program which may be used in developing frequency plans is included in Appendix H.

## 8.3 EQUIPMENT SELECTION CRITERIA

This section provides information to be used for the specification and selection of microwave systems and associated equipments. Table 8-4 summarizes the applicable performance standards for each subsystem and components.



AIAA 205

Figure 8-12. Troposcatter Frequency Plan Recommended by DCAC-330-175-1

Table 8-3. Microwave Bands Available for Federal Government Services Within U. S. A.

BAND NAME	RANGE GHz	CENTER FREQ GHz	ATT'N IN dB AT 1.0 MILE
2 GHz	1.71 - 1.85	1.780	101.6
	2.20 - 2.29	2.245	103.6
4 GHz	4.40 - 5.00	4.700	110.0
7-8 GHz	7.125 - 8.40*	7.750	114.4
14 GHz	14.40 - 15.25	14.825	120.0
* 7.25 - 7.30 GHz reserved for Satellite-to-Earth 7.975 - 8.025 GHz reserved for Earth-to-Satellite			

### 8.3.1 Antenna Systems

The antenna systems include:

- o Antenna feed
- o Antenna reflector
- o Transmission lines
- o Load isolators
- o Antenna tower

The most common antenna utilized in tropospheric scatter systems operating above 1 gigahertz is the parabolic reflector utilizing a horn feed.

Horn feeds are manufactured in both rectangular and circular configurations. The rectangular horn is energized from rectangular waveguide and the circular type from circular waveguide.

Feed devices are linearly polarized in either the vertical or horizontal plane (plane polarization), polarized in both planes (dual polarization), or circularly polarized (rotating). Feed methods for parabolic reflectors are classified as either front or rear feed.

These are illustrated in figure 7-7. For small antenna systems the feed horn is often an integral part of the reflector, but it is usually separate on larger dishes. This feature allows the feed polarization to be altered at installation.

Table 8-4. Specification of Major Items of Equipment  
(From CCTM 105-50 Army Manual, 1 June 1965, p. 4-184)

SUBSYSTEM AND COMPONENTS	FUNCTION	KEY PARAMETERS	APPLICABLE SPECIFICATIONS FROM STANDARDS	SPECIFIED BY SYSTEM DESIGNER
<p>Antenna</p> <p>Transmission Lines/Waveguide Duplexer Load Isolators Antenna Horns Antenna Reflector Dehydration &amp; Pressurization Equipment</p>	<p>Waveguides/transmission line transfer composite transmit signal from power amplifier to duplexer and from duplexer to antenna feed horn for radiation; transfer received composite signal from antenna feed horn to duplexer and from duplexer to receiver preamp.</p>	<p>1. Type 2. Characteristic Impedance 3. Gain loss from deflection 4. Beamwidth 5. Polarization separation 6. Front-to-back ratio 7. Gain 8. Side Lobe Level 9. VSWR 10. Power Handling Capability</p>	<p>1. Para 3.2.2.4.6.4.1, 3.2.2.4.6.4.1.4, 6-10, and -14 2. Para 3.2.2.4.6.4.1.1 3. Para 3.2.2.4.6.4.1.2 4. Para 3.2.2.4.6.4.1.3 5. Para 3.2.2.4.6.4.1.7 6. Para 3.2.2.4.6.4.1.8 7. Para 3.2.2.4.6.4.1.9 8. Para 3.2.2.4.6.4.1.10 9. Para 3.2.2.4.6.4.1.12 10. Para 3.2.2.4.6.4.1.13</p>	<p>Diversity type - dual or quadruple Diameter of reflector Type of transmission line Spacing for diversity</p>
	<p>Transmission Lines/Waveguide</p>	<p>1. Type 2. Attenuation 3. Characteristics Impedance 4. Pressurization and Leakage Rate 5. VSWR</p>	<p>1. Para 3.2.2.4.6.4.2 2. Para 3.2.2.4.6.4.2.1.1 and 3.2.2.4.6.4.2.2.1 3. Para 3.2.2.4.6.4.2.1.2 4. Para 3.2.2.4.6.4.2.1.3 and 3.2.2.4.6.4.2.2.4 5. Para 3.2.2.4.6.4.2.1.4 and 3.2.2.4.6.4.2.2.5</p>	
		<p>Duplexer</p>	<p>1. Para 3.2.2.4.6.4.3.1 2. Para 3.2.2.4.6.4.3.2 3. Para 3.2.2.4.6.4.3.3 4. Para 3.2.2.4.6.4.3.4 5. Para 3.2.2.4.6.4.3.4</p>	
<p>Transmitter</p> <p>Exciter Intermediate Power Amp. Power Amp</p>	<p>Generate carriers, modulate carrier with composite signal containing the information from each input channel and amplify modulated carrier to required level.</p>	<p>1. Operating frequency 2. Exciter frequency 3. Exciter Power Output 4. Frequency Tolerance 5. Carrier Frequency stability 6. RF bandwidth 7. RF extraneous and spurious emissions 8. Deviation Ratio 9. Deviation Capability 10. Input and Output Power of Power Amp. 11. Exciter, Power Amplifier Interface Impedance &amp; VSWR 12. Residual FM 13. Residual AM 14. RF Frequency Response 15. 2nd Harmonic, Output 16. Exciter - Baseband input impedance 17. Baseband input level 18. Reliability-MTBF 19. Intermodulation 20. Pre-emphasis/deemphasis 21. Receiver-transmitter Isolation</p>	<p>1. Para 3.2.2.4.6.1.5 and 3.2.2.4.6.1.2 of STDS 2. Para 3.2.2.4.6.1.5 of STDS 3. Para 3.2.2.4.6.2.3 of STDS 4. Para 3.2.2.4.6.2.1 of STDS 5. Para 3.2.2.4.6.1.5 of STDS 6. Para 3.2.2.4.6.2.11 of STDS 7. Para 3.2.2.4.6.2.2 of STDS 8. Para 3.2.2.4.6.2.4 of STDS 9. Para 3.2.2.4.6.2.5 of STDS 10. Para 3.2.2.4.6.2.6 of STDS 11. Para 3.2.2.4.6.2.8 of STDS 12. Para 3.2.2.4.6.2.7 of STDS 13. Para 3.2.2.4.6.2.10 of STDS 14. Para 3.2.2.4.6.2.12 15. Para 3.2.2.4.6.2.14 16. Para 3.2.2.4.6.2.16 17. Para 3.2.2.4.6.2.17 18. Para 3.2.2.4.6.2.18 19. Para 3.2.2.4.6.1.6 20. Para 3.2.2.4.6.1.7 21. Para 3.2.2.4.6.1.8</p>	<p>Operating Frequency Power Output Radio Frequency Bandwidth Deviation Capability</p>



Table 8-4. Specification of Major Items of Equipment (Continued)  
(From CCTM 105-50 Army Manual, 1 June 1965, p. 4-185)

<p><b>Receiver</b></p> <p>Low Noise Preamp Mixer IF Amplifier Crankline FM Demodulator</p>	<p>Detect transmitted signals, amplify them to prescribed level, separate and recover composite information signal through demodulation.</p>	<ol style="list-style-type: none"> <li>1. Front End Noise Figure</li> <li>2. Frequency Tolerance</li> <li>3. Spurious Receiver Response &amp; Image Rejection</li> <li>4. FM Threshold</li> <li>5. Receiver Noise Threshold</li> <li>6. IF Center Frequency</li> <li>7. IF Bandwidth</li> <li>8. IF Bandwidth Extension</li> <li>9. Diversity Combiner</li> <li>10. Automatic Gain Control</li> <li>11. Baseband Frequency Response</li> <li>12. Baseband Output Level</li> <li>13. Reliability-MTBF</li> </ol>	<ol style="list-style-type: none"> <li>1. Para 3-2.2.4.6.3-1</li> <li>2. Para 3-2.2.4.6.3-2</li> <li>3. Para 3-2.2.4.6.3-3</li> <li>4. Para 3-2.2.4.6.3-4</li> <li>5. Para 3-2.2.4.6.3-5</li> <li>6. Para 3-2.2.4.6.3-6</li> <li>7. Para 3-2.2.4.6.3-7</li> <li>8. Para 3-2.2.4.6.3-8</li> <li>9. Para 3-2.2.4.6.3-9</li> <li>10. Para 3-2.2.4.6.3-10</li> <li>11. Para 3-2.2.4.6.3-11</li> <li>12. Para 3-2.2.4.6.3-12</li> <li>13. Para 3-2.2.4.6.3-12</li> </ol>	<p>Bandwidth Type of Receiver Front end and Noise Figure</p>
<p><b>Multiplex</b></p> <p>Baseband Amplifiers Group-through Filters Group Mixers Group Distributing Frames Super Group Modems Multiplex Frequency Generator</p>	<p>Accept voice, telegraph and/or data channel outputs from terminal subsystems, heterodyne and amplify signals to provide composite, wide-band frequency-division signal to transmitter for carrier modulation.</p> <p>Accept received composite wideband frequency-division signal from receiver, separate and demodulate voice, telegraph and/or data channel signals comprising composite signal; amplify and provide channel information in original form for reproduction or transmission to user by termination subsystem.</p>	<ol style="list-style-type: none"> <li>1. Input and output impedances, levels and frequencies.</li> <li>2. Noise and interference.</li> <li>3. Envelope Delay Distortion.</li> <li>4. Total Noise.</li> <li>5. Harmonic Distortion</li> <li>6. Stability of multiple frequency generator.</li> <li>7. Net Loss Variation</li> <li>8. Gain Change for output level increase.</li> <li>9. Maximum Overall Change.</li> </ol>	<ol style="list-style-type: none"> <li>1. Table 3-2.2.4.1.2 of STDS.</li> <li>2. Para 3-2.2.4.2.2</li> <li>3. Para 3-2.2.4.1.1.2</li> <li>4. Para 3-2.2.4.1.1.3</li> <li>5. Para 3-2.2.4.1.1.4</li> <li>6. Para 3-2.2.4.1.1.9</li> <li>7. Para 3-2.2.4.1.1.6</li> <li>8. Para 3-2.2.4.1.1.5</li> </ol>	<p>Number and arrangement of channels, groups and supergroups.</p>
<p><b>Termination</b></p> <p>Circuit Condition Monitoring Facilities VU meters and other level indicators Distortion measuring equipment Patching facilities Distributing frames Filters and channel termination Signalling equipment Control monitoring equipment; i.e., fault alarm and automatic switching equipment</p>	<p>Interface control between and within multiplex subsystem and users line.</p>	<ol style="list-style-type: none"> <li>1. Input and output impedances, levels and frequencies.</li> <li>2. Noise.</li> </ol>	<ol style="list-style-type: none"> <li>1. Para 3-2.2.4.1.2 of STDS.</li> <li>2. Para 3-2.2.4.2.2</li> </ol>	<p>As required.</p>
<p><b>Power Generator</b></p> <p>Generators Switchgear Distribution Equipment Starting Equipment</p> <p>Environmental Control Heating and air conditioning Humidifiers and de-humidifiers Ventilation Air Filtering</p>	<p>Supply primary ac power for all technical electrical and electronic equipment and for all non-technical site requirements. Supply auxiliary power to technical load and various elements of non-technical load.</p> <p>Maintain proper environment - temperature, humidity etc. - for equipment.</p>	<ol style="list-style-type: none"> <li>1. Frequency regulation.</li> <li>2. Voltage regulation.</li> <li>3. Total load.</li> </ol> <ol style="list-style-type: none"> <li>1. Temperature</li> <li>2. Humidity</li> <li>3. Pressure</li> </ol>	<ol style="list-style-type: none"> <li>1. Para 3-6.1</li> <li>1. Para 3-6.3</li> </ol>	<p>Total primary power</p> <p>As required</p>

Parabolic reflectors for the antenna systems vary from 10 to 120 feet in diameter. The usual size is 10 to 30 feet with 60 and 120 foot units limited to extremely long and difficult paths. The beam-width is dependent upon the diameter and the transmitting frequency and varies from about 1.6 degrees for the larger ones. Radomes and heaters are not usually utilized on these larger antennas except in areas of extreme wind, snow or ice loading where distortion of the reflector (or tower) could substantially reduce the reliability of the path.

Tower construction and marking is detailed in chapter 15, in the Electronic Industries Association Standard RS-222A, and in Part 17 of the Rules and Regulations of the Federal Communications System.

Transmission lines between the transmitters and receiver and their associated antenna feeds are usually waveguides. Three types are available for use in microwave systems: standard rectangular, elliptical, and circular. A typical installation using these types of waveguides illustrating the various types of components is shown in figure 7-14. Table 8-1 lists the parameters of standard rigid rectangular waveguide. The use of flexible waveguide must be limited to only those areas where it is necessary and only short length should be considered due to the high attenuation.

For installations that utilize primary and standby microwave equipment, waveguide switches are used to connect either the primary or the standby equipment to the antenna, and to properly terminate the output of the unused equipment. Waveguide switches are usually electrically operated to provide for automatic switching applications.

A ferrite load isolator provides isolation between a signal source and its load with a resulting increase in power and improved frequency stability. The ferrite device accomplishes these results by reducing the standing wave ratio in the transmission line linking the signal source to the load. By placing the load isolator in the RF oscillator and receiver input circuits, the RF oscillator is effectively isolated from the two branches of the tee.

When it is necessary to couple two or three microwave equipments to a single antenna waveguide circulator is utilized. This device, illustrated in figure 7-16, is similar to a duplexer. With an antenna connected to one arm and three microwave equipments connected to the other arms, or two equipments and shorting plate connected to the other arms, the following apply:

Attenuation from arms 1 to 2, 2 to 3, 3 to 4, and 4 to 1 is approximately 0.5 dB in each instance.

Attenuation between other combinations of arms is on the order of 20 dB.

Installations of rigid line are pressurized and dehydrated to eliminate chances of moisture accumulation and resulting changes in impedance or short circuits within the run. Dehydration is extremely important in runs subject to temperature changes due to either climatic conditions or indoors/outdoors runs. Dehydration will be accomplished with an automatic compressor/dehydrator unit.

### 8.3.2 Radio Equipment

The radio equipment used in Tropospheric scatter is very similar to that described in chapter 7. The major differences are:

The receiver utilizes a low noise front end or preamplifier. Usually a parametric amplifier and/or a Tunnel Diode amplifier is used.

The transmitter utilizes a high power klystron amplifier to boost the transmitted power from 1 to 50 kilowatts or more.

### 8.3.3 Alarm Functions

Alarm functions similar to those used in line-of-sight systems are usually included in Tropo installations to allow rapid fault determination even through tropo installations are rarely unattended.

### 8.3.4 Multiplexing and Terminating Equipment

The system operation and performance will dictate the type, quantity and configuration of the multiples equipment used. If the system contains predominately one-way channels and no requirement exists for expansion of the return channel, do not provide these channels or limit the selection to equipment with common channel modems. Likewise, it should appear obvious that at a multi-direction terminal, complete multiplex terminal equipment for each direction of transmission should not be provided. Rather in this case, a common bay of equipment (correctly arranged with redundant amplifiers, power supplies and carrier oscillators) will be provided with separate banks of channelizing or grouping equipment for each path. Similarly at a location where there is no need for channel drops and a spur link may be provided, the correct design approach is to arrange the channelization and equipment for demodulating to the supergroup or group and pass through the station in the desired direction in this manner. The advantages gained by this procedure are economy and elimination of the noise that would be introduced in the modulation/demodulation process in the channel modems.

The multiplex equipment must be configured for the use of audio pads (usually 16 and 7 dB) external to the multiplex channel level adjustments to permit setting all circuits to the specified level at the "Zero Transmission Level Point." The need for synchronization, equalization, regulation and pilot tone interface also regulates the choices available for equipment configuration.

### 8.3.5 Standby Equipment

A high degree of reliability can be obtained in a microwave system when "standby" equipment is used to supplement the primary equipment. However, standby equipment should only be specified for stations where the greatest benefit will be realized, for

example, an isolated station difficult to reach under adverse conditions. Automatic switching equipment (as mentioned previously) is available to place the standby equipment operation if primary equipment fails. The use of standby equipment is minimal at Tropo scatter sites. Multiple equipments are utilized in the quadruple diversity normally used in most links. Failure of one piece of equipment only reduces the degree of diversity and not necessarily the performance over a limited period of time (unless it occurs during a time of high fading). This allows corrective maintenance without interruption of service.

#### 8.3.6 Spare Parts

During the course of preventive maintenance inspections, it will be noted from time to time that the performance of some components has deteriorated. Rather than wait for the component to become weaker or to fail completely and cause system interruptions, it is considered good maintenance practice to replace such weak components during the inspection. Although components are replaced before their full service life has been realized, service interruptions can be avoided in this manner. This practice will, in turn, increase the expected replacement parts cost for an operating system; however, the increase is justified on the basis of increased system reliability and the saving of additional manpower costs that would be incurred in making special rush trips to unattended stations to restore station operation.

Based on the known degree of component reliability of current installations, and considering a preventive maintenance program such as that described above, it can be expected that in a year's time a microwave system will require replacement parts equal in cost from 1 to 2 percent of the initial cost of the equipment, and replacement tubes equal in quantity from 25 to 30 percent of the total number of operating tubes. The tube replacement ratio, as noted above, is considerably higher than the part replacement ratio. This is generally to be expected because tubes have a higher failure incidence rate; and also, the relative performance of operating tubes is more easily checked than the relative performance of other components, so that more frequent tube replacements naturally result.

#### 8.3.7 Test Equipment

In order to properly test and service a microwave communications system, maintenance personnel should have a thorough understanding of the equipment's physical make-up, operational characteristics, capabilities, and limitations, and should be familiar with the circuit theory of operation. It is equally important that the proper test equipment be available for utilization by these personnel. Each field maintenance man should be equipped for making routine measurements. Typical equipments recommended for this purpose include a microwave test set, an IF/MF test set, a multimeter, and an oscilloscope; these units must be compatible with the microwave system in which they are used. As the area of maintenance progresses from on-site field maintenance, the quantity and requirements of the test equipment to perform the maintenance procedures will increase.

A list of test equipment for use in the alignment and adjustment of a typical microwave communications system is given in table 7-9. This list is for use with systems employing microwave equipment and time-division multiplex equipment. It includes the type of test equipment necessary, and the required characteristics of this equipment. Those pieces of equipment which are applicable for general field maintenance are indicated with an asterisk (\*).

Table 7-10 lists the test equipment required for laboratory (depot maintenance) measurements for a typical microwave system employing microwave equipment and time-division multiplex equipment. The item numbers under the EQUIPMENT NEEDED heading refer to the test equipment itemized in table 7-9.

### 8.3.8 Maintenance Tools

It is important that maintenance personnel have a thorough understanding of the equipment utilized in the system, and that they have the proper test equipment to perform the required maintenance checks. In addition to the above, the maintenance personnel must have the proper tools to efficiently repair the malfunctioning equipment when the defects are located. Of course, the maintenance man should know how to properly use the tools required for maintenance.

Table 7-11 lists the quantity and type of tools generally included in a tool kit required by a field serviceman to properly maintain a microwave communications system. In addition to these tools, the special tools indicated in the equipment manuals should be included.

Table 7-12 lists the type of tools required at a typical microwave station. The quantity of these tools will depend on the amount and type of equipment installed. The special tools indicated in the equipment manuals should also be included. Where the maintenance schedules require work on gasoline engine-operators, shelters, towers, etc., additional tools may be required, depending upon the type of equipment and hardware involved.

The tools required at a microwave system centralized maintenance depot are essentially the same as those required at a microwave station. However, the quantity of these tools will depend on the number of maintenance personnel assigned to the depot, the work load at the depot, and the type and quantity of equipment utilized in the system. In addition, special equipment such as a spray-painting equipment, a drill press, and other shop equipment may be required at the depot to facilitate the overhaul of the electronics and electrical equipment.

